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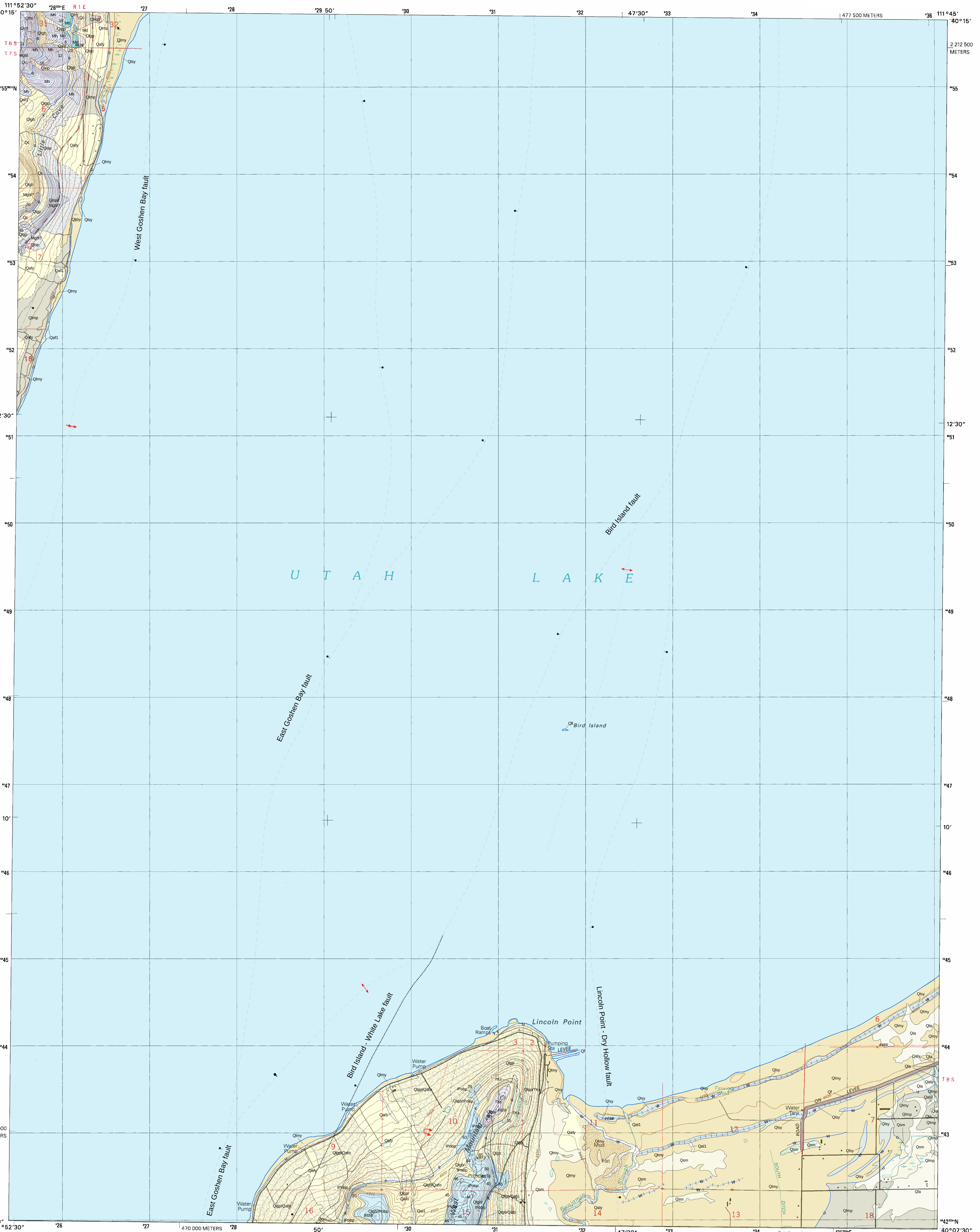

Scale 1:24,000

0°31′
9 MILS
13½°
240 MILS
GN
MN

UTM GRID AND 2001 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

CONTOUR INTERVAL 20 FEET
SUPPLEMENTARY CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
TO CONVERT FROM FEET TO METERS, MULTIPLY BY 0.3048

Interim Geologic Map of the Lincoln Point Quadrangle, Utah County, Utah
2008

by

Barry J. Solomon and Robert F. Biek

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UTAH

QUADRANGLE LOCATION

1	2	3	1 Saratoga Springs 2 Pelican Point 3 Orem
4		5	4 Soldiers Pass 5 Provo
6	7	8	6 Goshen Valley North 7 West Mountain 8 Spanish Fork

ADJOINING 7.5' QUADRANGLE NAMES

Base map from U.S. Geological Survey
Lincoln Point 7.5' quadrangle, 1997
Base map in NAD 1927
Aerial Photo and Field Mapping: Barry J. Solomon and Robert F. Biek, 2006-2007
Digital Cartography: Paul Kuehne

INTERIM GEOLOGIC MAP OF THE LINCOLN POINT QUADRANGLE, UTAH COUNTY, UTAH

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Disclaimer

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OPEN-FILE REPORT 526
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
2008

INTRODUCTION

Location and Geographic Setting

The Lincoln Point quadrangle covers the south-central part of Utah Lake in Utah Valley and includes the eastern edge of the Lake Mountains, with Little Cove, and the northern part of West Mountain, with Lincoln Point at its northern tip (figure 1). Bird Island in Utah Lake is about 2 miles (3 km) north of Lincoln Point. State Route 68 follows the lake shore adjacent to the Lake Mountains and Lincoln Beach Road follows the lake shore adjacent to West Mountain.

Geologic Summary

Bedrock Stratigraphy and Geologic Structure

The bedrock of the Lincoln Point quadrangle consists of sedimentary rocks of Tertiary to Mississippian age. These sedimentary strata are exposed in the northwest corner of the quadrangle at the base of the Lake Mountains and along the southern edge of the quadrangle near Lincoln Point on the north end of West Mountain. Utah Lake separates the Lake Mountains from West Mountain and is underlain by several geologic structures.

Lake Mountains: Strata of Late Mississippian age crop out on the slope of the Lake Mountains in the northwest corner of the Lincoln Point quadrangle. The strata are poorly exposed below the highest (Bonneville) shoreline of late Pleistocene Lake Bonneville due to a veneer of lacustrine gravel. Regionally, the Mississippian beds are part of the faulted eastern limb of the Lake Mountains syncline (Bullock, 1951) and lie on the upper plate of a reverse fault mapped to the west in the adjacent Soldiers Pass quadrangle (Biek and others, 2006). The rocks are in the footwall of a normal fault at the base of the Lake Mountains inferred from gravity data (Floyd, 1993; Cook and others, 1997).

West Mountain: Middle Pennsylvanian rocks are poorly exposed below the Bonneville shoreline on the limbs of an overturned anticline with its axis near Lincoln Point at the northern tip of West Mountain. Sedimentary rocks of Late Cretaceous to Paleocene (?) age cap the upper part of the point. West Mountain is in the footwall of the Dry Hollow fault to the east (Cook and others, 1997).

Structures under Utah Lake: Utah Lake, a remnant of Lake Bonneville, separates West Mountain from the Lake Mountains. Utah Lake is underlain by both east- and west-dipping faults forming the western boundary of Utah Valley, with the Wasatch fault zone forming the eastern boundary. Cook and Berg (1961) recognized the probable existence of faults on the floor of Utah Lake based on the measurement of gravity anomalies in the vicinity of Utah Valley. The first conclusive evidence of active faulting within the Utah Lake fault zone was based on the acoustical-profiling survey of Brimhall and others (1976), which showed pronounced displacements of Bonneville lake sediments less than 16,000 years old. Brimhall and Merritt (1981) mapped several faults and folds beneath Utah Lake based on widely spaced seismic reflection transects. Baskin and Berryhill (1998) conducted a seismic investigation of the shallow subsurface sediments in the Lincoln Point-Bird Island area of Utah Lake using a continuous, high-resolution profiler. Their data show that faulting is prominent in the study area, with mostly minor displacements, but they did not map faults between profiles. Baskin and others (1994) noted that springs in the Lincoln Point-Bird Island area are all near bedrock faults inferred by Cook and Berg (1961) and faults mapped by Brimhall and others (1976) that displace lake-bottom sediments, and proposed that the faults and associated joints may play an important role in the location of warm springs in the area.

Cook and others (1997, p. 9, footnote 4) accepted "…the location and sense of displacements of the faults mapped specifically along the transects on plate 1 by Brimhall and others (1976)…" but questioned the interpretations of Brimhall and Merritt (1981) because, in their opinion, mapped faults were extrapolated over longer distances than were justified by the data and the extrapolation was made without regard to maintaining a consistent sense of fault displacement. Although the location of the faults are uncertain and the interpretation of data upon which they were mapped was questioned by Cook and others (1997), the structures mapped in the Lincoln Point quadrangle by Brimhall and Merritt (1981) are shown on our map to indicate the presence of lakebed faulting. These structures trend northeast and include the West Goshen Bay fault (a normal fault that extends southward into a monocline), the East Goshen Bay normal fault about 2 miles (3 km) farther east, the Bird Island-White Lake fault on the west margin of Lincoln Point (an extension of the concealed fault mapped by Clark [2006] on the west side of West Mountain), an unnamed down-to-the-east normal fault that bifurcates from the East Goshen Bay fault, an anticline that may merge with the Bird Island fault and that may represent a relay ramp between two en echelon faults, and the Lincoln Point-Dry Hollow fault (a normal fault northeast of Lincoln Point that extends northward from the geophysical fault mapped by Clark [2006] on the east side of West Mountain).

Acoustical profiles show from less than 7 to 16 feet (<2 to 5 m) of displacement across individual faults and folds beneath the lake in a persistent 25- to 50-foot-deep (8-15-m-) layer identified as the Provo Formation by Brimhall and Merritt (1981). Machette (1992) interpreted the layer as lake-bottom sediments probably deposited during the regressive phase of Lake Bonneville. The displacements occurred in the past 14 to 16 ka (period of the Bonneville regression) and indicate slip rates from < 0.1 to about 0.4 millimeters/year (Black and others, 2003). The reflection profiles suggest that displacements decrease upward in strata above the marker horizon, indicating episodic or recurring movement on the faults. Displacements occur up to within several feet of the lake bottom, but there is no evidence of displaced surficial Lake Bonneville deposits onshore along the Bird Island-White Lake and Lincoln Point-Dry Hollow faults (Clark, 2006).

Quaternary Geology

The surficial sediments in the Lincoln Point quadrangle were mostly deposited by latest Pleistocene Lake Bonneville (Currey and Oviatt, 1985; Oviatt and others, 1992), in part contemporaneously with the last glacial advance (the Pinedale glaciation; Lips and others [2005] date the Pinedale maxima from about 17 to 15 ka based on ^{10}Be exposure ages measured from moraines at Little Cottonwood Canyon in the Wasatch Range). A thin veneer of Lake Bonneville deposits overlies coalesced older (middle to upper Pleistocene) alluvial fans that underlie piedmont slopes on the margins of West

Mountain, and thicker Lake Bonneville deposits are mapped near Little Cove. Remnants of the older alluvial-fan deposits are exposed above and slightly below the highest Lake Bonneville shoreline at the base of the Wasatch Range east of the Lincoln Point quadrangle (Machette, 1992).

Other surficial deposits in the quadrangle are younger than Lake Bonneville and reflect post-glacial landscape evolution. Incision of the lake threshold in southern Idaho and warming climatic conditions reduced the size of Lake Bonneville, leaving remnants such as Utah Lake stranded in Bonneville sub-basins (Jarrett and Malde, 1987; O'Conner, 1993). Utah Lake deposits, mapped below the elevation of its threshold of 4500 feet (1372 m) at the northern end of the lake, are found on the margins of the Lake Mountains and West Mountain, and in a small embayment east of West Mountain. Younger stream alluvium was also deposited as the lake level fell and small alluvial fans formed at the mouths of range-front drainages. Wind eroded the desiccated Bonneville lake beds and deposited a thin but widespread mantle of calcareous loess on stable geomorphic surfaces. The loess is friable to moderately firm, homogenous, nonstratified, and porous, and forms steep to vertical faces where exposed in stream cuts; most argillic B horizons of late Pleistocene-age soils in the region are derived from this loess (Machette, 1992). The loess is from 3 to 5 feet (1-1.5 m) thick.

Lake Bonneville

Deposits and shorelines of Pleistocene Lake Bonneville are prominent features of the surficial geology of the Lincoln Point quadrangle. Lake Bonneville was a large pluvial lake that covered much of northwestern Utah between about 32,500 and 11,600 calendar years ago (references and radiocarbon ages for this discussion of the chronology of Lake Bonneville are shown in table 1; Oviatt and Thompson [2002] summarized many recent changes in the interpretation of Lake Bonneville radiocarbon chronology). Four regionally extensive shorelines of Lake Bonneville are found in the Bonneville Basin (Gilbert, 1890), but only the two most prominent (the Bonneville and Provo shorelines) are found in the quadrangle (table 1). The earliest of the regional shorelines is the Stansbury, which resulted from a climatically induced lake-level oscillation from about 24,400 to 23,200 years ago during expansion of Lake Bonneville. The Stansbury shoreline formed at elevations below those in the quadrangle. The lake continued to rise, entering the Lincoln Point quadrangle from the north at an elevation of about 4500 feet (1372 m) about 23,000 years ago. In the Bonneville Basin, the lake reached its highest level of about 5092 feet (1552 m) about 18,000 years ago; this level was controlled by an overflow threshold near Zenda, in southern Idaho. This highstand created the Bonneville regional shoreline, which forms a small bench north of Little Cove in the northwest corner of the Lincoln Point quadrangle.

About 16,800 years ago, overflow and rapid erosion at the Zenda threshold resulted in catastrophic lowering of the lake by 340 feet (100 m) (Jarrett and Malde, 1987) in less than one year (O'Conner, 1993). Lake Bonneville then stabilized at a new lower threshold near Red Rock Pass, Idaho, and the Provo regional shoreline was formed. The Provo shoreline is mapped on slopes of the Lake Mountains and West Mountain in the Lincoln Point quadrangle.

The lake oscillated at or near the Provo level until about 13,500 years ago (Godsey and others, 2005), when climatic factors induced further lowering of the lake level within the Bonneville Basin. As Lake Bonneville fell below the altitude of the natural threshold of Utah Valley at the northern end of Utah Lake, Utah Lake became isolated from the main body of Lake Bonneville (Machette, 1992). By about 13,000 years ago, the level of Lake Bonneville had fallen below the elevation of present Great Salt Lake, but a subsequent expansion of Lake Bonneville from about 12,800 to 11,600 years ago formed the Gilbert shoreline. During the Gilbert expansion of Lake Bonneville, threshold control of the level of Utah Lake prevented the lake level from similarly rising (Machette, 1992). By Holocene time (about 10,000 years ago) Lake Bonneville had fallen to near the current level of Great Salt Lake, leaving Great Salt Lake and Utah Lake as its two most prominent remnants.

Isostatic rebound following overflow of Lake Bonneville, as well as displacement along the Wasatch fault zone, uplifted regionally extensive shorelines in the Bonneville basin (Crittenden, 1963; Currey, 1982). The amount of isostatic uplift increases toward the center of the basin where the volume of removed water was greatest; Crittenden (1963) estimated a maximum isostatic uplift of 210 feet (64 m) near the Lakeside Mountains west of Great Salt Lake. Machette (1992) reported combined isostatic and fault uplift of the Bonneville and Provo shorelines as much as 110 feet (34 m) and 65 feet (20 m), respectively, along the Wasatch fault zone in eastern Utah Valley. In the Lincoln Point quadrangle, shorelines are not affected by displacement of the Wasatch fault zone, which lies at least 10 miles (16 km) to the east, and isostatic uplift of both shorelines is less than the maximum combined uplift recorded by Machette (1992). The maximum elevation of the Bonneville shoreline in the Lincoln Point quadrangle is about 5160 feet (1575 m) compared to its threshold elevation of 5092 feet (1552 m) at Zenda, and the maximum elevation of the Provo shoreline in the quadrangle is about 4780 feet (1455 m) compared to its threshold elevation of 4737 feet (1444 m) at Red Rock Pass (table 1). Thus, isostatic uplift of the Bonneville and Provo shorelines in the quadrangle is about 68 feet (23 m) and 43 feet (11 m), respectively.

Previous Investigations

Several investigators have mapped parts of the geology of the Lincoln Point quadrangle. Bullock (1951) produced a reconnaissance geologic map of the Lake Mountains, including the small part of the range extending into the northwest corner of the quadrangle. White (1953) mapped the geology of West Mountain, including its northern tip at Lincoln Point, and Hintze (1962) compiled a small-scale bedrock map of the southern Wasatch Range that also extended to West Mountain. Paul D. Proctor, late Professor of Geology at Brigham Young University, while under contract to the Utah Geological Survey, created an unpublished draft map of the Lincoln Point quadrangle, including the geology of both the Lake Mountains and West Mountain portions of the quadrangle. Geophysical investigations of Utah Lake include seismic reflection transects and acoustical profiles of the lake (Brimhall and others, 1976; Brimhall and Merritt, 1981), a Bouguer gravity survey (Floyd, 1993; Cook and others, 1997), and collection of high-resolution seismic-reflection data (Baskin and Berryhill, 1998). Baskin and others (1994) studied the hydrogeology and water quality of the Lincoln Point-Bird Island area.

The geology of Quaternary deposits in the Lincoln Point quadrangle was mapped at reconnaissance scale by Bissell (1963), who conducted the first geologic mapping of surficial deposits in the region. Miller (1982) remapped the deposits. Machette (1992) mapped the surficial geology of eastern Utah Valley, including the Lincoln Point quadrangle east of West Mountain, as part of a program by the U.S. Geological Survey to map the surficial geology of the active Wasatch fault zone.

This mapping effort is part of a larger project to map the Provo 30' x 60' quadrangle, during which the geology of the adjacent Goshen Valley North (Clark and others, 2006), Saratoga Springs (Biek, 2004), Soldiers Pass (Biek and others, 2006), Spanish Fork (Solomon and others, 2007), West Mountain (Clark, 2006), and Provo (Solomon and Machette, 2008a) quadrangles were mapped. Solomon and Machette (2008b) also mapped the Quaternary geology of the Utah Valley part of the Springville quadrangle, and Solomon mapped the Quaternary geology of part of the Spanish Fork Peak quadrangle in 2006 (unpublished). Mapping of the Quaternary geology of the Pelican Point, Orem, and Bridal Veil Falls quadrangles is ongoing (figure 2).

ACKNOWLEDGEMENTS

The late Dr. Paul Proctor (Brigham Young University) contracted with the UGS to map the Lincoln Point and adjacent West Mountain quadrangles in the mid 1980s. He, along with Wenxia Wang (temporary adjunct research associate professor at BYU), conducted preliminary field work that was not completed, as Dr. Proctor subsequently fell into ill health. His field maps and notes were provided to the UGS in 1999 after his death. We acknowledge his efforts and improvements to the understanding of the geology of this region.

We thank Donald Clark (UGS) for his guidance regarding interpretation of bedrock geology and geologic structure. UGS staff members Gary Christenson, Grant Willis, Donald Clark, and Robert Ressetar improved this map through their reviews. UGS staff members Paul Kuehne and Jim Parker assisted in preparation of the map and supporting materials.

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qal_1 **Level-1 stream deposits** (upper Holocene) – Moderately sorted pebble and cobble gravel in a matrix of sand, silt, and minor clay, containing thin discontinuous sand lenses; mixtures of sand, silt, and clay on gentler slopes; subangular to rounded clasts; thin to medium bedded. Deposited near the mouth of Benjamin Slough and by small streams on the west slope of West Mountain; includes deposits on active flood plains and minor terraces less than 5 feet (1.5 m) above stream level; locally includes minor colluvial deposits along steep stream embankments; equivalent to the younger part of young stream deposits (Qaly), but differentiated where modern deposits with active channels and bar-and-swale topography can be mapped separately. Exposed thickness less than 15 feet (5 m).

Qaly **Young stream deposits, undivided** (Holocene to upper Pleistocene) – Moderately sorted sand, silt, and clay with minor pebble gravel. Deposited by Benjamin Slough and other small streams east of West Mountain; includes upper Pleistocene to middle Holocene stream deposits incised by active stream channels and partly overlain by level-1 stream deposits (Qal_1) that cannot be differentiated because of map scale, and upper Pleistocene to Holocene deposits in areas where their specific age cannot be determined; postdates regression of Lake Bonneville from the Provo shoreline and lower levels. Thickness variable, probably less than 15 feet (5 m).

Qalp **Stream deposits, regressive (Provo) phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted pebble and cobble gravel in a matrix of sand, silt, and minor clay; contains thin discontinuous sand lenses; subangular to rounded clasts; thin to medium bedded. Deposited in small, steep washes near Little Cove in the northwest corner of the Lincoln Point quadrangle, where deposits grade to the Provo shoreline and are locally incised by modern washes. Exposed thickness less than 15 feet (5 m).

Qaf_1 **Level-1 alluvial-fan deposits** (upper Holocene) – Poorly to moderately sorted, weakly to non-stratified, pebble to cobble gravel in a matrix of sand, silt, and minor clay; clasts angular to subrounded, with sparse well-rounded clasts derived from Lake Bonneville gravel; medium to very thick bedded. Deposited by debris flows, debris floods, and streams at the mouths of small, intermittent stream channels that drain bedrock and lacustrine deposits near Little Cove; equivalent to the younger part of young alluvial-fan deposits (Qafy) but differentiated where modern deposits of small, active, discrete fans are found at the mouths of stream channels incised into young alluvial fans, are not incised by younger channels, and can be mapped separately. Exposed thickness less than 10 feet (3 m).

Qafy **Young alluvial-fan deposits, undivided** (Holocene to upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel with boulders near bedrock sources, in a matrix of sand, silt, and clay, grading to mixtures of sand, silt, and clay on gentler slopes. Deposited by debris flows, debris floods, and streams at the mouths of small mountain canyons and streams locally incising Lake Bonneville deposits, where alluvial-fan deposits typically form a coalesced apron at the base of the Lake Mountains and Lincoln Point. Includes level-1 (Qaf_1) and older alluvial-fan deposits that postdate the regression of Lake Bonneville from the Provo shoreline and lower levels that cannot be differentiated because of map scale, or are in areas where the specific age of Holocene deposits cannot be determined; no Lake Bonneville shorelines are found on these alluvial fans, although Utah Lake shorelines cut some fans near Utah Lake. Thickness variable, probably less than 40 feet (12 m).

Fill deposits

Qf **Artificial fill** (Historical) – Engineered fill used in the construction of levees at Lincoln Point; unmapped fill is locally present in all developed areas but only the largest deposits are mapped. Maximum thickness about 20 feet (6 m).

Qfm **Mine-dump deposits** (Historical) – Waste rock and overburden from calcite prospects near Little Cove; as much as about 30 feet (9 m) thick.

Colluvial deposits

Qc **Colluvial deposits** (Holocene to upper Pleistocene) – Pebble, cobble, and boulder gravel, commonly clast supported, in a matrix of sand, silt, and clay; angular to subrounded clasts, poorly sorted, poorly stratified, locally derived sediment deposited by slopewash and soil creep on moderate slopes and shallow depressions near Little Cove; because many bedrock slopes are covered by at least a veneer of colluvium, only the larger, thicker deposits are mapped. Maximum thickness about 20 feet (6 m).

Lacustrine deposits

Deposits younger than the Bonneville lake cycle: Only mapped below the Utah Lake highstand elevation of about 4495 to 4500 feet (1370-1372 m) (table 1).

Qlt **Lacustrine tufa** (Holocene to upper Pleistocene) – White to light-gray, calcareous tufa, spongy to dense, with rare mollusk shells. Mapped on Bird Island (noted by Paul Proctor in his unpublished draft manuscript for the Lincoln Point quadrangle, but not field checked); unmapped tufa is found as a thin coating on young lacustrine silt and clay (Qlmy) below the Utah Lake highstand near

Lincoln Point (Bissell, 1963). Thickness unknown, but maximum thickness is likely less than 3 feet (1 m).

Qlsy **Young lacustrine sand and silt** (Holocene to upper Pleistocene) – Well-sorted, fine to medium sand and silt that forms bars and barrier beaches near the shore of Utah Lake. Maximum thickness about 5 feet (1.5 m).

Qlmy **Young lacustrine silt and clay** (Holocene to upper Pleistocene) – Silt, clay, and minor fine-grained sand deposited along the margin of Utah Lake; locally organic rich and includes pebbly beach gravel; overlies sediments of the Bonneville lake cycle. Brimhall and others (1976) reported that Holocene gray clayey silt composed mostly of calcite forms the upper 15 to 30 feet (5-10 m) of the lake sediment in Utah Lake.

Deposits of the regressive (Provo) phase of the Bonneville lake cycle: Only mapped below the Provo shoreline, which is at elevations from about 4750 to 4780 feet (1450-1455 m) in the quadrangle (table 1). Currey (1982) estimated an elevation of 4770 feet (1454 m) for the Provo shoreline on a southeast-facing beach ridge on Lincoln Point (SE1/4 section 10, T. 8 S., R.1 E., Salt Lake Base Line and Meridian [SLBLM]). The B soil horizon of paleosols developed on regressive-phase lacustrine deposits commonly shows an intensification of brown colors due to oxidation of iron-bearing minerals or a slight accumulation of clay, and may include a pedogenic accumulation of calcium carbonate as filaments in fine-grained soil or thin, discontinuous coatings on gravel; Machette (1992), using the terminology of Birkeland (1984), designated the soil profile of these units as A/Bw/Bk(or Cox) to A/Bt(weak)/Bk(or Cox).

Qlgp **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, clast-supported, pebble to cobble gravel and pebbly sand with minor silt. Gastropods locally common in sandy lenses; gravel commonly cemented with calcium carbonate (tufa); thin to thick bedded. Near Little Cove, deposits typically form wave-cut or wave-built benches; wave-cut benches are commonly partly covered by colluvium derived from adjacent oversteepened slopes. At the northern tip of West Mountain, deposits likely overlie bedrock at shallow depth (map units IPobp and TKs), and large boulders of quartzite and limestone as much as 6 feet (2 m) in diameter from Tertiary-Cretaceous strata (TKs) lie on the surface of the slope, likely eroded from upslope outcrops. Bedding ranges from horizontal to primary dips of 10 to 15 degrees on steeper piedmont slopes; intermediate shorelines are locally well developed on Provo-level deposits; commonly interbedded with or laterally gradational to lacustrine sand and silt of the regressive phase (Qlsp) in the Lake Mountains. Exposed thickness less than 30 feet (10 m).

Qlsp **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel. Thick to very thick bedded, commonly laminated, with some ripple marks and scour features; gastropods locally common. Deposited in relatively shallow water near shore; overlies and grades downslope into lacustrine silt and clay of the regressive phase (Qlmp); locally buried by loess veneer. Exposed thickness less than 30 feet (10 m).

Qlmp **Lacustrine silt and clay** (upper Pleistocene) – Calcareous silt (marl) and clay with minor fine sand; typically laminated or thin bedded; ostracodes locally common. Deposited in quiet water in moderately deep parts of the Bonneville basin and in sheltered bays; overlies lacustrine silt and clay of the transgressive phase of Lake Bonneville and grades upslope into lacustrine sand and silt (Qlsp); locally concealed by loess veneer; regressive lacustrine shorelines typically poorly developed. Forms irregular erosional remnants surrounded by younger deposits in the southeast corner of the Lincoln Point quadrangle and linear deposits parallel to steeper slopes along the base of the Lake Mountains. Machette (1992) reported that silt and clay of the regressive phase can be differentiated from silt and clay of the transgressive phase by the presence of conchoidal fractures in blocks of transgressive deposits and their absence in regressive deposits, but Qlmp may include some undifferentiated transgressive deposits. Exposed thickness less than 15 feet (5 m), but total thickness may exceed several tens of feet.

Deposits of the transgressive (Bonneville) phase of the Bonneville lake cycle: Mapped between the Bonneville and Provo shorelines. The Bonneville shoreline is at elevations from about 5140 to 5160 feet (1565-1575 m) in the quadrangle (table 1). The B soil horizon of paleosols developed on transgressive-phase lacustrine deposits commonly shows a slight to moderate accumulation of clay and may include a pedogenic accumulation of calcium carbonate as filaments in fine-grained soil or thin, discontinuous coatings on gravel; Machette (1992), using the terminology of Birkeland (1984), designated the soil profile of these units as A/Bt/Bk(or Cox).

Qlgb **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, clast-supported pebble to cobble gravel in a matrix of sand and silt; locally interbedded with thin to thick beds of silt and pebbly sand. Clasts commonly subrounded to rounded, but some deposits consist of poorly sorted, angular gravel derived from nearby bedrock outcrops. Gastropods locally common in sandy lenses; gravel locally cemented with calcium carbonate (tufa). Thin to thick bedded; bedding ranges from horizontal to primary dips of 10 to 15 degrees on steeper piedmont slopes; commonly covered by a thin veneer of colluvium. Commonly present on wave-cut benches at the highest (Bonneville) shoreline in bedrock in the Lake Mountains, and mapped above the Provo shoreline at the north end of West Mountain. Exposed thickness less than 30 feet (10 m).

Mass-movement deposits

Qmt **Talus deposits** (Holocene to upper Pleistocene) – Very poorly sorted, angular cobbles and boulders and finer-grained interstitial sediment deposited principally by rock fall on or at the base of steep slopes; mapped in the Lake Mountains above the Bonneville shoreline. Generally less than 20 feet (6 m) thick.

Spring and marsh deposits

Qsm **Marsh deposits** (Holocene to upper Pleistocene) – Fine, organic-rich sediment associated with springs, ponds, seeps, and wetlands; commonly wet, but seasonally dry; may locally contain peat deposits as thick as 3 feet (1 m); overlies and grades into fine-grained lacustrine deposits (Qlmp and Qlmy); present where water table is high east of West Mountain. Thickness commonly less than 10 feet (3 m).

Mixed-environment deposits

Qla **Lacustrine and alluvial deposits, undivided** (Holocene to upper Pleistocene) – Sand, silt, and clay in areas of mixed alluvial and lacustrine deposits that are undifferentiated because the units grade imperceptibly into one another; mapped east of West Mountain. Thickness less than 10 feet (3 m).

Stacked-unit deposits

Qlgp/Qafo

Lacustrine gravel and sand (regressive phase) over older alluvial-fan deposits, undivided (upper Pleistocene/upper to middle Pleistocene) – A veneer of lacustrine gravel and sand related to the regressive phase of Lake Bonneville reworked from underlying alluvial-fan deposits older than Lake Bonneville composed of poorly sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; mapped below the Provo shoreline on the flanks of West Mountain. Lacustrine deposits are generally less than 3 feet (1 m) thick.

Qlgp/TKs

Lacustrine gravel and sand (regressive phase) over Tertiary-Cretaceous strata (upper Pleistocene/Paleocene? to Upper Cretaceous?) – Conglomerate and pebbly sandstone concealed by a veneer of lacustrine gravel and sand related to the regressive phase of Lake Bonneville; mapped below the Provo shoreline on the northern end of West Mountain (Lincoln Point). Lacustrine deposits are generally less than 10 feet (3 m) thick.

Qlgp/IPobp

Lacustrine gravel and sand (regressive phase) over Butterfield Peaks Formation, Oquirrh Group (upper Pleistocene/Middle to Lower Pennsylvanian) – Rock of the Butterfield Peaks Formation partly concealed by a discontinuous veneer of lacustrine gravel and sand related to the regressive phase of Lake Bonneville; mapped below the Provo shoreline on West Mountain (Lincoln Point). Lacustrine deposits are generally less than 3 feet (1 m) thick.

Qlsp/Mgbl?

Lacustrine sand and silt (regressive phase) over the Long Shale Trail Member and lower limestone member of the Great Blue Limestone (upper Pleistocene/Upper Mississippian) – Rock of the lower part (?) of the Great Blue Limestone partly concealed by a discontinuous veneer of lacustrine sand and silt related to the regressive phase of Lake Bonneville; mapped south of Little Cove (Lake Mountains). Lacustrine deposits are generally less than 3 feet (1 m) thick.

Qlgb/Qafo

Lacustrine gravel and sand (transgressive phase) over older alluvial-fan deposits, undivided (upper Pleistocene/upper to middle Pleistocene) – A veneer of lacustrine gravel and sand related to the transgressive phase of Lake Bonneville reworked from underlying alluvial-fan deposits older than Lake Bonneville composed of poorly sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; mapped between the Bonneville and Provo shorelines on West Mountain (Lincoln Point). Lacustrine deposits are generally less than 3 feet (1 m) thick.

Qlgb/TKs

Lacustrine gravel and sand (transgressive phase) over Tertiary-Cretaceous strata (upper Pleistocene/Paleocene? to Upper Cretaceous?) **–** Conglomerate and pebbly sandstone mostly concealed by a veneer of lacustrine gravel and sand related to the transgressive phase of Lake Bonneville; mapped between the Bonneville and Provo shorelines on the northern end of West Mountain (Lincoln Point). Lacustrine deposits are generally less than 10 feet (3 m) thick.

Qlgb/IPobp

Lacustrine gravel and sand (transgressive phase) over Butterfield Peaks Formation, Oquirrh Group (upper Pleistocene/Middle to Lower Pennsylvanian) – Rock of the Butterfield Peaks Formation partly concealed by a discontinuous veneer of lacustrine gravel and sand related to the transgressive phase of Lake Bonneville; mapped between the Bonneville and Provo shorelines on West Mountain (Lincoln Point). Lacustrine deposits are generally less than 3 feet (1 m) thick.

Major unconformity

TERTIARY – CRETACEOUS

TKs **Tertiary-Cretaceous strata** (Paleocene? to Upper Cretaceous?) – Reddish-orange clast-supported conglomerate with rounded to well-rounded pebbles to small boulders of limestone and sandstone in subequal amounts; limestone clasts are light gray to bluish gray, are locally cherty or fossiliferous, and may be derived principally from Pennsylvanian or Mississippian strata; locally contains subangular to subrounded sandstone and limestone boulders 3 to 6 feet (1-2 m) in diameter; forms resistant ledge and low outcrops planed off by wave action near the Provo shoreline at the northern end of West Mountain, but is mostly concealed by shoreline gravels associated with the transgressive and regressive phases of Lake Bonneville; even so, the distribution of large boulders and well-rounded limestone clasts suggests that this conglomerate likely underlies much of the northern end of West Mountain, possibly northeastward to Lincoln Point. Similar unit mapped by Clark (2006) near the crest of West Mountain; age unknown, but may correlate to the North Horn Formation, Uinta Formation, or Tibble Formation (Clark, 2006; Constenius and others, 2006). Similar strata are present in the southern Wasatch Range and northern Long Ridge (Hintze, 1962), where they are as much as about 600 feet (180 m) thick (Metter, 1955); maximum exposed thickness is about 50 feet (15 m), but thickness may exceed 400 feet (120 m) in the Lincoln Point quadrangle.

Major unconformity

Because Paleozoic map units in the Lincoln Point quadrangle are small extensions of much larger exposures in adjacent quadrangles, thicknesses of Paleozoic units are described from adjacent quadrangles where more complete sections are exposed.

PENNSYLVANIAN

The Oquirrh Group/Formation was deposited in the Oquirrh marine basin of north-central Utah and southern Idaho, with fine arkosic sand derived principally from the Weber shelf and Uncompahgre Uplift (Welsh and Bissell, 1979). Terminology and subdivision of Oquirrh Group/Formation and associated Permian strata vary by thrust plate and location within the Oquirrh basin (Welsh and James, 1961; Tooker and Roberts, 1970; Swenson, 1975; Morris and others, 1977; Welsh and Bissell, 1979; Jordan and Douglas, 1980; Hintze, 1988, p. 34; Biek, 2004; Biek and Lowe, 2005) because a comprehensive regional study of the basin has not been conducted. Thus, differing terminology is commonly applied west and east of Utah and Salt Lake Valleys (figure 3). On the west side of the valleys, including the Lincoln Point quadrangle, the Pennsylvanian strata of the Oquirrh Group are divided into three formations; these are, in ascending order, the West Canyon Limestone, Butterfield Peaks Formation, and Bingham Mine Formation. On the east side of the valleys, the Oquirrh Formation is divided into, in ascending order, four Pennsylvanian units: the Bridal Veil Limestone Member, Bear Canyon Member, Shingle Mill Limestone Member, and Wallsburg Ridge Member. The Oquirrh Formation also includes the Permian Granger Mountain Member (Baker and Crittenden, 1961; Baker, 1964a, 1972a).

The Oquirrh Group forms the bulk of West Mountain and nearby Lake Mountains, which extend into the Lincoln Point quadrangle, and is composed principally of calcareous sandstone, sandy limestone, limestone, and minor orthoquartzite. Only part of the Butterfield Peaks Formation is present in the Lincoln Point quadrangle, and is exposed only on West Mountain (Lincoln Point). The ages of Oquirrh Group units are from Webster and others (1984), Davis and others (1994), Biek (2004), and Clark (2006). The Pennsylvanian Oquirrh Group is in excess of 17,800 feet (5425 m) thick in the Oquirrh Mountains (Tooker and Roberts, 1970).

Oquirrh Group

IPobp **Butterfield Peaks Formation** (Middle and Lower Pennsylvanian [Desmoinesian – uppermost Morrowan]) – Consists of very fine to fine-grained, medium- to thick-bedded calcareous sandstone with planar, low-angle, and ripple cross-stratification; sandstone is light brownish gray to medium gray and olive gray on fresh surfaces but weathers to grayish orange to brown; the sandstone is commonly non-calcareous on weathered surfaces and so appears similar to orthoquartzite, but fresh surfaces are invariably calcareous; Butterfield Peak strata are present below the elevation of the Bonneville shoreline and are thus mostly covered by a discontinuous veneer of lacustrine deposits. Only a few hundred feet of the upper part of the formation is exposed in this quadrangle; the incomplete thickness of the formation in the Lake Mountains is as much as 4500 feet (1370 m) (Biek, 2004); Clark (2006) reported that the formation is in excess of 7300 feet (2200 m) thick at West Mountain, but the base is not exposed; Tooker and Roberts (1970) reported the complete formation is 9070 feet (2765 m) thick in the Oquirrh Mountains.

Not in contact

MISSISSIPPIAN

In the Lincoln Point quadrangle, strata of Mississippian age are only exposed in the Lake Mountains.

Mgbl, Mgbl?

Great Blue Limestone, lower unit, undivided (Upper Mississippian) – Includes, in descending order, Long Trail Shale Member and lower limestone member. Forms poorly exposed slopes in the northwest corner of the Lincoln Point quadrangle and is queried and undivided due to structural complexity. **Long Trail Shale Member** is interbedded, reddish-brown, dark-gray, and grayish-purple calcareous and locally carbonaceous shale, and thin-bedded, medium-gray limestone and fossiliferous limestone; contains locally abundant rugose corals, pelecypods, brachiopods, and bryozoans; weathers to form strike valleys and saddles; locally contains limonite pseudomorphs after pyrite; neither the lower nor upper contact of the Long Trail Shale Member is well exposed, but regionally both appear conformable and gradational; Gordon and others (2000) reported a thickness of 108 feet (33 m) for the Long Trail Shale Member in the southern Oquirrh Mountains; the member is about 90 feet (28 m) thick in the Lake Mountains (Bullock, 1951). **Lower limestone member** is medium to very thick bedded, light- to dark-gray but typically medium-gray limestone and fossiliferous limestone; upper part is typically thin-bedded and platy-weathering argillaceous limestone and interbedded gray to grayish-purple shale; bryozoans are locally abundant; the lower limestone member is 850 feet (260 m) thick in the southern

Oquirrh Mountains (Gordon and others, 2000), but appears to be only about 300 feet (90 m) thick in the Lake Mountains (Biek, 2004; Biek and others, 2006).

Mh **Humbug Formation** (Upper Mississippian) – Interbedded calcareous quartz sandstone, orthoquartzite, and limestone that weather to ledgy slopes. Sandstone is light to dark brown weathering, pale yellowish brown to olive gray, medium to very thick bedded, variably calcareous or siliceous, locally with planar or low-angle cross-stratification. Limestone rarely contains dark-gray chert nodules and is: (1) light gray weathering, medium dark gray, medium to thick bedded, and fine grained with local small white chert blebs; (2) dark gray, very thick bedded with small white calcite blebs; or (3) locally medium to coarse grained with sparse fossil hash. Upper half contains several distinctive, ledge-forming, white, medium- to thick-bedded sublithographic limestone beds as much as 10 feet (3 m) thick. Upper contact is conformable and gradational and represents a change from interbedded sandstone and limestone to limestone; age from Morris and Lovering (1961); about 700 to 750 feet (210-230 m) thick near the west shore of Utah Lake (Biek, 2004).

Md **Deseret Limestone** (Upper to Lower Mississippian) – Only uppermost part is exposed in the northwest corner of the Lincoln Point quadrangle. Medium- to very thick bedded, medium-dark-gray, variably sandy and fossiliferous limestone; contains distinctive white calcite nodules and blebs and local to common brown-weathering chert nodules and brown-weathering bands (case-hardened surfaces); fossils include rugose corals, uncommon brachiopods, crinoids, bryozoans, and fossil hash; locally contains few thin calcareous sandstone beds. Upper contact is conformable and gradational and corresponds to a change from locally fossiliferous limestone to predominantly sandstone; age from Morris and Lovering (1961) and Sandberg and Gutschick (1984); about 700 to 750 feet (210-230 m) thick in Lake Mountains (Biek, 2004).

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Table 1. *Ages of major shorelines of Lake Bonneville and Utah Lake and shoreline elevations in the Lincoln Point quadrangle.*

Lake Cycle and Phase	Shoreline (map symbol)	Age		Elevation feet (meters)
		radiocarbon years B.P.	calendar years B.P.[1]	
Lake Bonneville				
Transgressive Phase	Stansbury	22,000-20,000[2]	24,400-23,200	Not present
	Bonneville (B)	15,500-14,500[3]	18,000-16,800	5140-5160 (1565-1575)
	flood			
Regressive Phase	Provo (P)	14,500-12,000[4]	16,800-13,500[5]	4750-4780 (1450-1455)
	Gilbert	11,000-10,000[6]	12,800-11,600	Not present
Utah Lake				
	Utah Lake highstand (U)	12,000-11,500[7]	-----	4495-4500 (1370-1372)

[1]Calendar-calibrated ages of most shorelines have not been published. Calendar-calibrated ages shown here, except for the age of the end of the Provo shoreline, are from D.R. Currey, University of Utah (written communication to Utah Geological Survey, 1996; cal yr B.P. = 1.16 ^{14}C yr B.P.).

[2]Oviatt and others (1990). Currey (written communication to Utah Geological Survey, 1996) assumed a maximum age for the Stansbury shoreline of 21,000 ^{14}C yr B.P., which is used in the conversion to calendar years.

[3]Oviatt and others (1992), Oviatt (1997).

[4]Godsey and others (2005) revised the timing of the occupation of the Provo shoreline and subsequent regression; Oviatt and others (1992) and Oviatt (1997) proposed a range from 14,500 to 14,000 ^{14}C yr B.P. Oviatt and Thompson (2002) summarized many recent changes in the interpretation of the Lake Bonneville radiocarbon chronology.

[5]Calendar-calibrated age of the end of the Provo shoreline estimated by interpolation from data in Godsey and others (2005), table 1, who used Stuiver and Reimer (1993) for calibration.

[6]Murchison (1989), figure 20.

[7]Estimated from data in Godsey and others (2005); Machette (1992) estimated the age of the regression of Lake Bonneville below the Utah Valley threshold at 13,000 ^{14}C yr B.P. from earlier data.

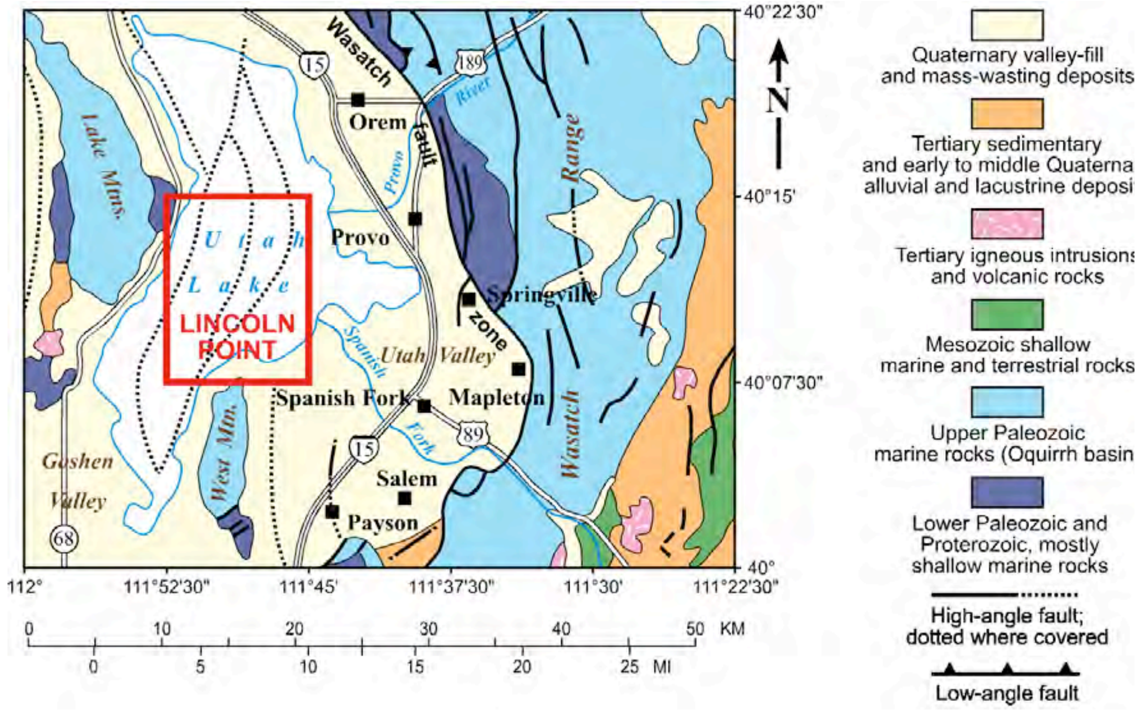


Figure 1. Index map showing the primary geographic features and generalized geology in the vicinity of the Lincoln Point quadrangle.

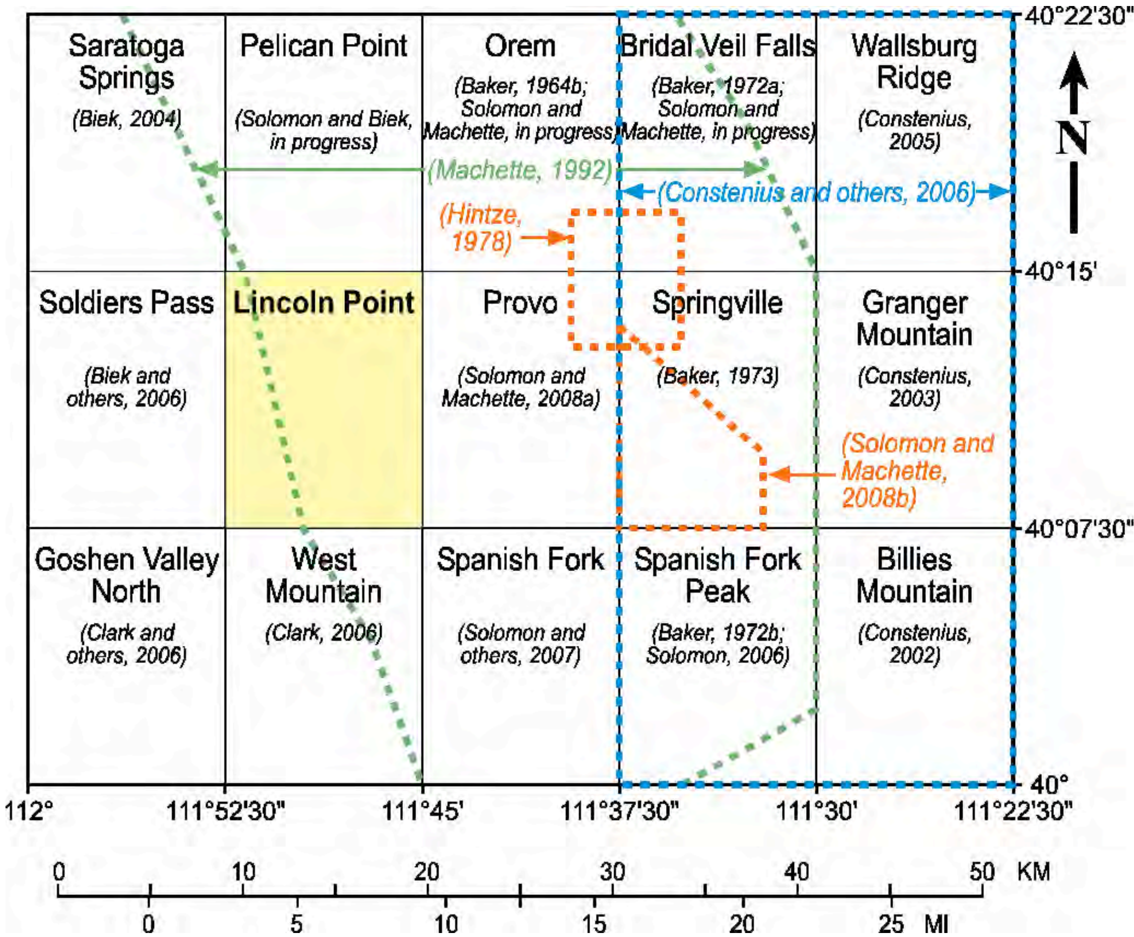


Figure 2. Index map showing selected geologic maps available for the Lincoln Point and surrounding 7.5' quadrangles.

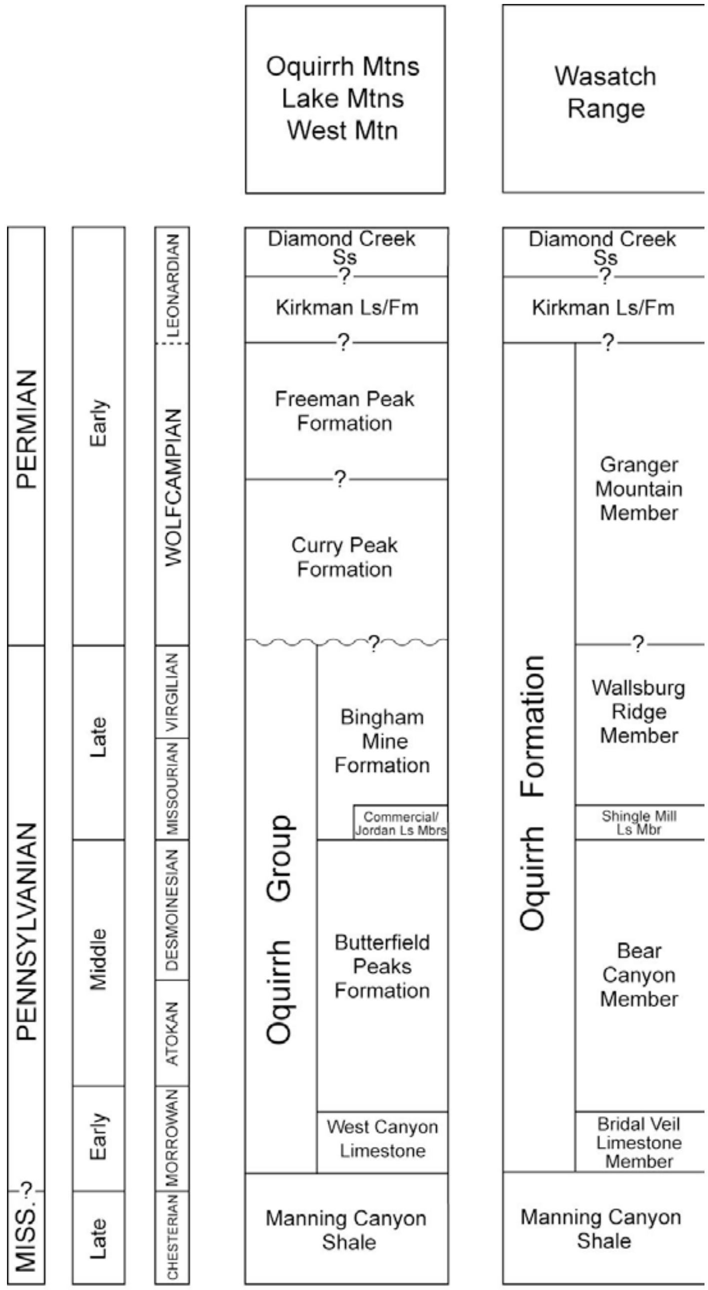
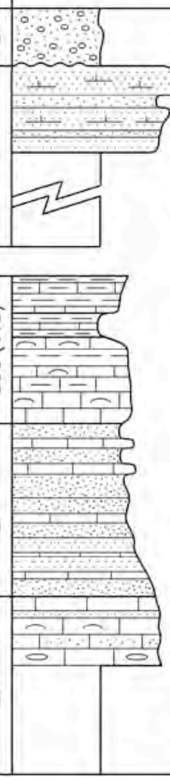


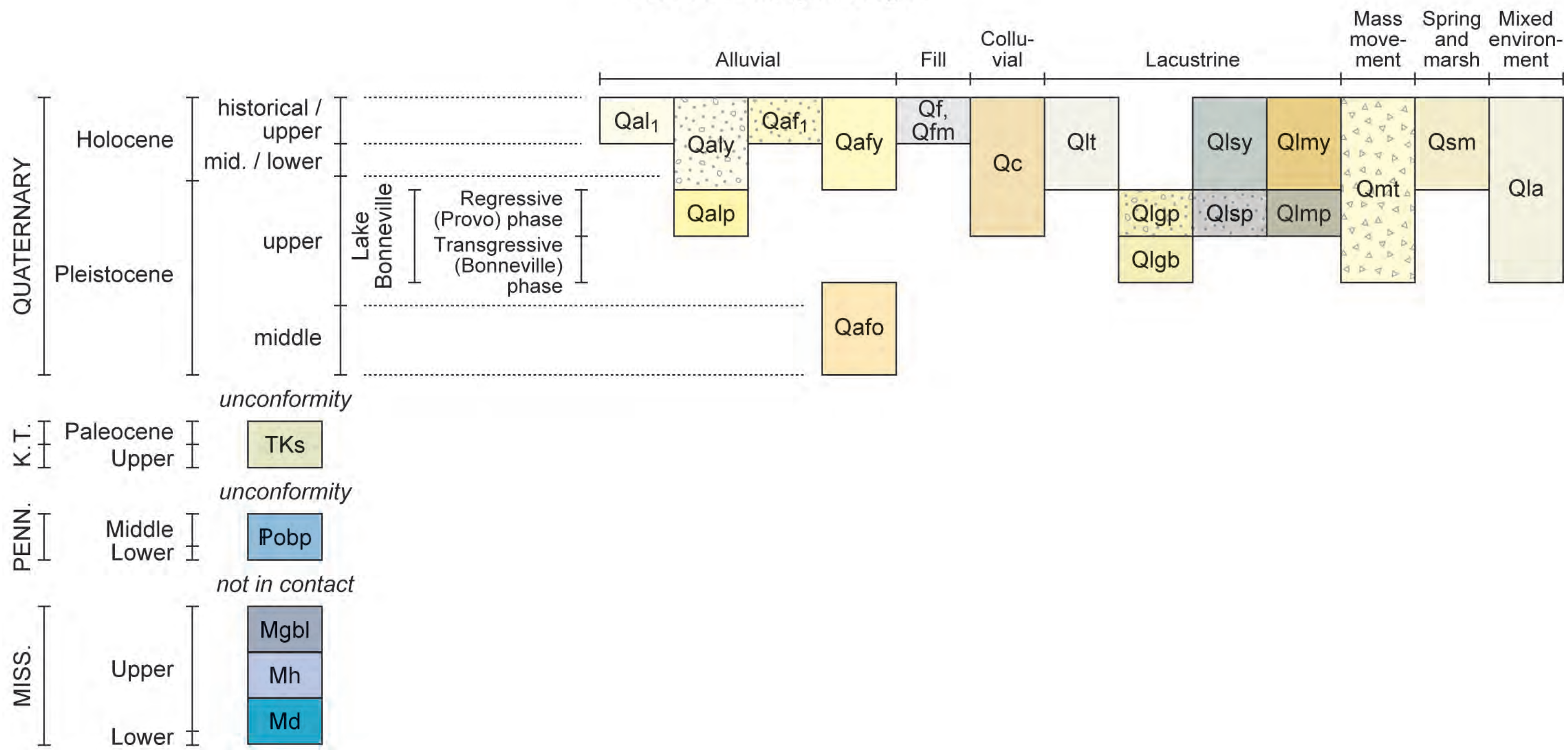
Figure 3. Comparison of stratigraphic nomenclature for the Oquirrh Formation/Group and associated strata near Salt Lake and Utah Valleys, north-central Utah.

LITHOLOGIC COLUMN
Lincoln Point Quadrangle

SYSTEM	SERIES	STAGE	GROUP, FORMATION, AND MEMBER		SYMBOL	THICKNESS Feet (Meters)		LITHOLOGY
T.? / K.?	Paleocene? / U.?		Tertiary-Cretaceous strata		TKs	50+ (15+)		Lincoln Point area
PENNSYLVANIAN	Middle / L.	Desmoinesian / Morr.	Oquirrh Group	Butterfield Peaks Formation	ℙobp	9070 (2765)		Not exposed
NOT IN CONTACT								
MISSISSIPPIAN	Upper / L.		Great Blue Limestone	Long Trail Shale Member and lower limestone member, undivided	Mgbl	90 (28) / 300 (90)	390 (118)	Limonite pseudomorphs; *Spirifer* brachiopods; Platy weathering
			Humbug Formation		Mh	700-750 (210-230)		White sublithographic limestone
			Deseret Limestone		Md	700-750 (210-230)		White calcite blebs; Not exposed



CORRELATION OF MAP UNITS
Lincoln Point Quadrangle



GEOLOGIC SYMBOLS
Lincoln Point Quadrangle

Contact – Dashed where approximately located

Normal fault – Concealed; inferred principally from gravity data (Floyd, 1993; Cook and others, 1997) and shallow sonar-like data (Brimhall and Merritt, 1981); very approximately located; bar and ball on down-dropped side

Axial trace of overturned anticline – Dotted where concealed and approximately located

Axial trace of anticline – Concealed; inferred principally from shallow sonar-like data (Brimhall and Merritt, 1981); very approximately located

Axial trace of monocline – Concealed; inferred principally from shallow sonar-like data (Brimhall and Merritt, 1981); very approximately located

Lacustrine shorelines – Mapped at the wave-cut bench of erosional shorelines and the top of constructional bars and barrier beaches; may coincide with geologic contacts:

Lake Bonneville shorelines –

B Bonneville shoreline

P Provo shoreline

Utah Lake shorelines –

U Pleistocene highstand shoreline of Utah Lake

W Other shorelines of Utah Lake

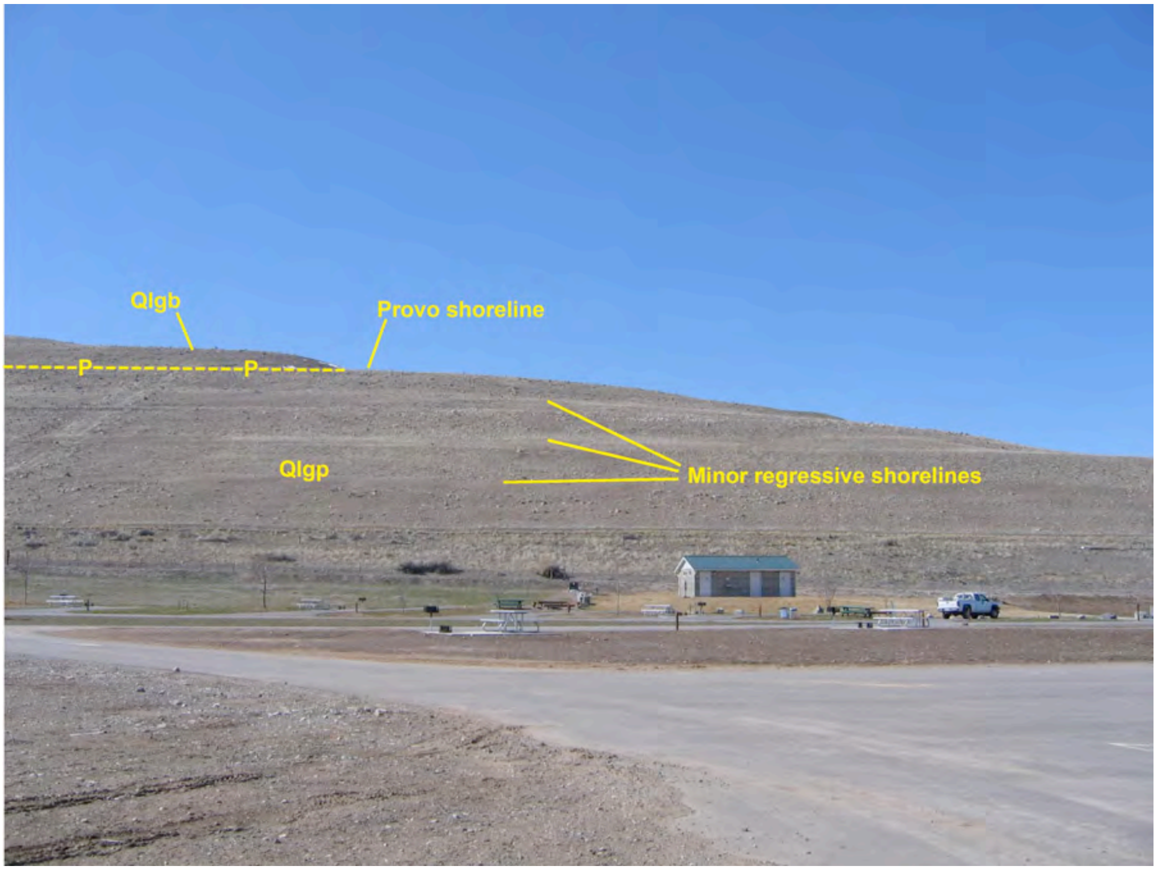
Crest of lacustrine barrier beach or spit

20 Strike and dip of inclined bedding

20 Strike and dip of overturned bedding

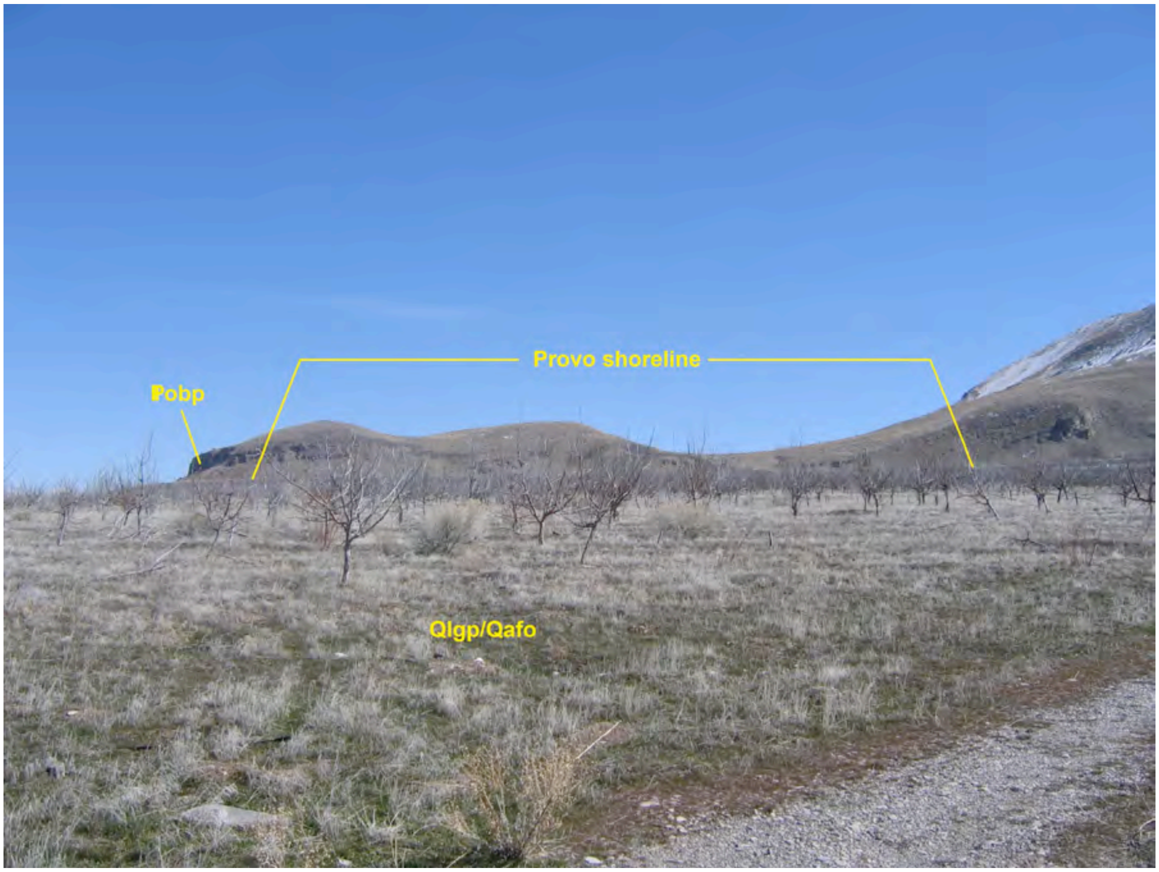
Approximate strike and dip of inclined bedding

Sand and gravel pit



The east side of Lincoln Point at the northern end of West Mountain. The Provo shoreline forms a bench near the top of Lincoln Point; minor regressive shorelines of Lake Bonneville are etched downslope. Transgressive lacustrine gravel and sand (Qlgb) is above the Provo shoreline and regressive gravel and sand (Qlgp) is below the shoreline. Isolated resistant outcrops of Tertiary-Cretaceous conglomerate (TKs) are found near the Provo shoreline at Lincoln Point, but are too small to be seen in this photograph.

View to the west of the east-central Lake Mountains across ice-covered Utah Lake. Transgressive deposits of Lake Bonneville (Qlgp, Qlsp, and Qlmp) form a fringe surrounding the mountains, and underlie Little Cove in the Lincoln Point quadrangle, Big Cove in the adjacent Soldiers Pass quadrangle, and Pelican Point in the adjacent Pelican Point quadrangle. The limestone quarry, also in the Pelican Point quadrangle, is in the Mississippian Deseret Limestone (Md), which extends into the northwestern corner of the Lincoln Point quadrangle, north of Little Cove.



Northwest side of Lincoln Point. The Provo shoreline of Lake Bonneville forms a bench, with a resistant ledge of the Pennsylvanian Butterfield Peaks Formation (IPobp) above the bench and transgressive lacustrine gravel and sand (Qlgp) below the bench. The lacustrine deposits form a thin veneer that is reworked from underlying Pleistocene alluvial-fan deposits older than Lake Bonneville (Qafo).